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Bankruptcy Cost, Financial Structure and Technological Flexibility Choices[*]

Marcel Boyer[†], Armel Jacques[‡], Michel Moreaux[§]

Résumé / Abstract

Nous étudions dans cet article les interactions entre la structure de financement des firmes et leur choix technologique, en particulier leur flexibilité technologique. Lorsqu'il existe des coûts de faillite, une firme endettée peut modifier ses choix stratégiques afin de diminuer sa probabilité de faillite. Nous montrons, dans le cas où la capacité de la technologie inflexible est faible (élevée), que l'endettement d'une firme peut conduire cette dernière à choisir une technologie moins (plus) flexible. Ces effets de l'endettement sur les choix technologiques peuvent, dans un oligopole, faire l'objet d'un choix stratégique. Nous montrons qu'il existe des cas où l'endettement est utilisé par les firmes comme un outil de collusion partielle et d'autres cas où l'endettement améliore la position stratégique d'une firme au détriment de sa concurrente.

We study the interactions between the capital structure and the technological flexibility choices of firms in a duopoly. When there are bankruptcy costs, a leveraged firm may modify its strategic choices in order to decrease its probability of bankruptcy. We show that, when the capacity level of the inflexible technology is small (large), debt may induce firms to choose less (more) flexible technologies. Debt may be used in a strategic way. We show that debt can be used as a partial collusion tool to increase the expected profits of both firms. We show also that a firm may use debt as a commitment device to increase its own expected profit to the detriment of its rival.

Mots Clés : Endettement, flexibilité, oligopole

Keywords: Capital structure, flexibility, oligopoly

JEL: L13, G32

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1 Introduction

According to many business gurus and commentators, flexibility has become the Holy Grail in the 'new' economic or business environment because developments in globalization, in information technologies and in manufacturing technologies have made the markets significantly more volatile. The increased flexibility is obtained through reengineering, outsourcing, downsizing, focusing on core competencies, investing in computer controlled flexible technologies, empowering key individuals with specific human capital, and more generally designing more powerful incentive systems and corporate governance rules to ensure better congruence of interests throughout the firm. Business International (1991) claims that the search for flexibility is the all-inclusive concept allowing an integrated understanding of most if not all recent developments in management theory. It claims also that reorganizing a firm to increase its flexibility requires a concerted effort on many levels: introducing flatter organizational structures, investing in automated manufacturing, creating strong but malleable alliances, introducing decision and incentive systems centered on results, etc. In the words of economic theorists, this means harnessing and exploiting the supermodularity in the set of strategies.

We reconsider here these claims in a context of oligopolistic competition under uncertainty in order to clarify the issues pertaining to the relationships between flexibility, financial structure and bankruptcy costs. As we will see, flexibility has both positive and negative features and therefore the choice of its level in a corporation raises more subtle strategic issues than suggested in the gurus' writing and in the management literature in general. In terms of investment, a flexible manufacturing system capable of producing a wider array or scope of products will typically be more expensive than a dedicated manufacturing system, not only in terms of the investment cost per se but also in terms of its impact on the internal organization of the firm and on its relations with suppliers and customers.[1] The evaluation of the proper flexibility spectrum in a firm, whether this flexibility comes from technological, organizational or contractual characteristics and decisions, requires an evaluation of the fine trade-off between the value and cost of changes in the real options portfolio so created, in the probability of bankruptcy, in the probability of

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[1]See Gerwin (1982, 1993), Mensah and Miranti (1989), Milgrom and Roberts (1990) and Boyer and Moreaux (1997) for convincing examples.

being preempted in significant markets, and of changes in the behavior of competitors, actual and potential, who may be more or less aggressive towards the firm depending on its level of flexibility. The analysis of these issues requires modeling strategic competition with explicit and specific features related to flexibility.

In that vein, we consider a duopolistic context with endogenous capital structures and technological flexibility choices in which firms can fall into costly bankruptcy. In such a context, one expects that the debt level can change the technological flexibility choice of a firm since the latter modifies in an important way the distribution of cash flows over the different states of demand. In turn, it implies first that debt may be used strategically and second that the financial and technological choices of a firm are simultaneously determined.

Brander and Lewis (1986) show that the debt level may have a significant impact in a strategic context. In an oligopolistic market under uncertain demand conditions, limited liability induces firms to take more risky positions as in Jensen and Meckling (1976). The debt level works as a credible commitment device. By increasing its debt level, a firm can, at the Cournot stage of the game, decrease the equilibrium production level of its rival while increasing its own production level: debt has a strategic value. With bankruptcy costs, the link between debt and production is more ambiguous: Brander and Lewis (1988) show that debt can either increase or decrease the competitive position of the firm. Several other authors have contributed to clarifying the effects of the capital structure on the production level of a firm in an oligopoly: in some contexts, debt improves the competitive position of the firm but in others, debt is a source of weakness.[2]

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[2]Maksimovic (1988) analyses the impact of debt on the possibilities to sustain collusion. Poitevin (1989, 1990) argues that debt may allow to signal low production cost. Glazer (1994) solves a two period model in which debt is repaid at the end of the last period; in the second period debt is pro-competitive but, in the first period, debt allows some kind of collusion because an increase in the rival's profit decreases its residual debt and make it less aggressive in the last period. Showalter (1995, 1999) analyses the Bertrand competition case; he shows that the optimal strategic debt choice depends on the type of uncertainty that exists in the output market: if costs are uncertain, firms do not leverage but, if demand conditions are uncertain, firms carry positive strategic debt levels in order to soften competition. In an entry framework, the incumbent wants to commit credibly to choose a low price in order to deter entry, hence to be in debt if costs are uncertain and debt free if demand is uncertain. In a similar framework, Schnitzer and Wambach (1998) investigate the choice between inside and outside financing by risk-averse entrepreneurs who produce with uncertain production costs. Parsons (1997) expands the model of Brander and Lewis (1988) by allowing corner solutions; with this specification, firms may initially have an incentive to decrease output levels if they take on more debt. Hughes, Kao and Mukherji (1998) show that the possibility to acquire and share information may destroy Brander and Lewis's (1986) result. Dasgupta and Shin (1999) show that, when one firm has better access to information, leverage may be a way for the rival firm to free-ride on the firm's information. In Bolton and Scharfstein (1990), debt decreases the probability that the firm will survive and therefore increases the probability that rivals will prey on it.

All these studies assume a given technology, more precisely a given cost function. But as emphasized by Stigler (1939), firms have some degrees of freedom in choosing their cost functions. In this spirit, Vives (1989), Lecostey (1994) and Boyer and Moreaux (1997) among others show that a way to commit to a production strategy in an oligopolistic market with uncertain demand conditions is to choose an inflexible technology. The trade-off in this case is that a firm choosing an inflexible technology can, if the capacity of the inflexible technology is relatively low [high], reduce the market share of its rival in states of low [high] demand but cannot fully exploit [but shuts down in] the states of high [low] demand. In the present paper, we consider oligopolistic market settings and we analyze the technological choice and the financial structure as joint strategic decisions.

The paper is organized as follows. We present the model in section 2. We derive in section 3 the profits of the firms for given technologies and we infer the debt contracts and the debt thresholds of bankruptcy. In section 4, we study the impact of debt on the technological flexibility choices. In section 5, we discuss the strategic value of being in debt and the existence of jointly optimal capital and technological structures. We conclude in section 6.

2   The model

The inverse demand function is assumed to be linear:[3]

$$p = \max(0, \alpha - \beta Q)$$

where Q is the aggregate output and α is a random variable taking two values, α_1 with probability μ and α_2 with probability $1 - \mu$, with $\alpha_2 > \alpha_1$.

Firms choose between two available technologies: one is inflexible (i) and the other is flexible (f). An inflexible firm either produces x, where x is the exogenous capacity, or shuts down. A flexible firm can choose any positive level of production. The two technologies have the same average operating cost c, but the sunk costs differ. The sunk cost of an inflexible technology is K; this cost may be composed of product design costs, land purchases, plant construction costs,

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[3]Demand linearity and all the other specific assumptions as constant marginal cost are made only to get tractable explicit solutions. The reader will understand that our assumptions could be relaxed at the cost of more complexity and less transparency in the results.

marketing cost, and so on. The sunk cost of a flexible technology is $K + H$ where $H > 0$.

Initially, entrepreneur $h \in \{1, 2\}$ has a capital of A_h. This capital level is exogenous, an assumption we will relax in section 5. If A_h is less than K or $K + H$, the entrepreneur must borrow additional capital from a bank. Banks can observe each firm's technological flexibility choice but neither the level of demand nor the profits of the firms.[4] So a debt contract specifies a level of repayment R independent of the level of demand and profit but dependent on the technological choices of both firms. If a firm is unable to repay R, it goes bankrupt and its gross profit is seized by the bank. For matter of simplicity, we avoid introducing incentive constraints in the problem by assuming that in case of bankruptcy, courts can check the books of the firm, find the liars and impose on them harsh punishment.[5] We assume also that the banking sector is perfectly competitive and therefore a bank accepts a contract if and only if the expected repayment is at least equal to the payoff which would be obtained in lending at the riskless interest rate, normalized at zero.

The entrepreneurs have limited liability but bankruptcy generates non-monetary costs for an entrepreneur since bankruptcy sends a bad signal on his management skills, making it harder for him to find a new job or to borrow new capital to finance another project. Furthermore, bankruptcy generates high transaction costs. These costs are assumed to have a monetary equivalent value B, independent of the level of default.

The two entrepreneurs begin the game with observable amounts of equity A_1 and A_2. The timing of the game is as follows. First, the entrepreneurs simultaneously negotiate debt contracts as *functions* of the technological configuration to emerge in the industry. Second, they choose simultaneously their respective technology. Hence, the debt contracts and the technologies, or the flexibility levels, are chosen simultaneously within a firm and across firms. Third, they observe the level of demand and engage in Cournot competition. Finally, firms repay debt or go bankrupt. Regarding the exogenous capacity level x, we assume that in the high state of demand, both firms produce and avoid bankruptcy at the Cournot stage of the game whatever their technological choices, that is $x < (\alpha_2 - c)/2\beta$. They may go bankrupt in the low state of

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[4]This assumption of unobservability of profits is introduced so as to make the standard debt contract optimal (see Bolton and Scharfstein 1990).

[5]In other words, profits are unobservable by banks but verifiable by courts, an assumption which can be justified by the investigation power of courts as compared to banks.

demand. More precisely, we consider the following three possible cases:

- $x \in X_1 \equiv \{x \mid x < (\alpha_1 - c)/2\beta\}$ (small capacity): when demand is low, both firms produce at the Cournot stage of the game for any technological choices;

- $x \in X_2 \equiv \{x \mid (\alpha_1 - c)/2\beta < x < (\alpha_1 - c)/\beta\}\}$ (intermediate capacity): when demand is low, technological configurations (f, f) and (f, i) imply the same equilibria as when $x \in X_1$, whereas (i, i) implies that one firm shuts down and the other obtains its monopoly profit;

- $x \in X_3 \equiv \{x \mid (\alpha_1 - c)/\beta < x\}$ (large capacity): when demand is low, technological configuration (f, f) implies the same equilibria as above, (f, i) implies that the inflexible firm shuts down whereas the flexible firm enjoys a monopoly profit level, and (i, i) implies that both firms shut down.

This model is the simplest possible tractable strategic model capturing the relevant characteristics of the 'new' economic or business environment as discussed above, of the interdependence between financial structure and technology choice (endogenous cost function), and of optimal financial contracting under asymmetric information (adverse selection) and bankruptcy cost.

3   The expected profits as functions of technological choices

Debt levels play a crucial role in the product competition stage because it determines the probability of bankruptcy. We characterize in this section the debt threshold, over which the firm cannot repay its debt in the bad state of demand, as a function of technological configurations. For $t, t' \in \{i, f\}$ and any $X \in \{X_1, X_2, X_3\}$, we shall denote by $\pi_k(t, t', X)$ the profit of a firm with technology t facing a rival with technology t' when $x \in X$ and $\alpha = \alpha_k \in \{\alpha_1, \ \alpha_2\}$, by $E\Pi(t, t', X)$ the expected profit of a firm before the demand level is revealed, and by $D(t, t', X)$ the debt threshold over which the firm goes bankrupt when the demand is low. The Cournot equilibrium profits over operating costs, as functions of the technological choices of the firms, are given in Appendix A.

3.1 Financial contract and expected profit of a flexible firm

When demand is low, the gross profit of a flexible firm is equal to $\pi_1(f, t', X)$ which defines the debt threshold[6]

$$D(f, t', X) = \pi_1(f, t', X) \tag{1}$$

Thus if the debt of the firm is lower than $D(f, t', X)$, the firm never goes bankrupt. The banking sector is perfectly competitive and so the repayment R_h is equal to the amount borrowed $K + H - A_h$.

$$R_h = K + H - A_h. \tag{2}$$

On the other hand, if the firm's debt is larger than $D(f, t', X)$, the firm goes bankrupt when demand is low. In this bad state of the market, the firm repays only its gross profit, an amount lower than the amount it should repay. So in the good state, the firm must repay an amount R_h such that the expected profit of the bank is equal to zero, that is $\mu \pi_1(f, t', X) + (1 - \mu) R_h = K + H - A_h$. Hence, R_h as a function of (f, t') is given by:

$$R_h = \frac{1}{1 - \mu} \left[K + H - A_h - \mu \pi_1(f, t', X) \right]. \tag{3}$$

We can obtain the expected profit as follows. For low debt levels, the firm never goes bankrupt and its expected profit is $\mu \pi_1(f, t', X) + (1 - \mu) \pi_2(f, t', X) - R_h - A_h$ where R_h is given by (2). For large debt levels, the firm goes bankrupt if demand is low; its expected profit is $(1 - \mu) [\pi_2(f, t', X) - R_h] - \mu B - A_h$ where R_h is now given by (3). Thus, making use of (2) and (3), we obtain that the expected profit of the entrepreneur is given by:

$$E\Pi(f,\ t',\ X) = \begin{cases} \widehat{E\Pi}(f, t', X), & \text{if } K + H - A_h \leq D(f, t', X) \\ \widehat{E\Pi}(f, t', X) - \mu B, & \text{if } K + H - A_h > D(f, t', X) \end{cases} \tag{4}$$

where $\widehat{E\Pi}(f, t', X)$ is the expected profit when the firm does not go bankrupt:

$$\widehat{E\Pi}(f, t', X) = [\mu \pi_1(f, t', X) + (1 - \mu) \pi_2(f, t', X)] - (K + H). \tag{5}$$

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[6]When a flexible firm faces an inflexible firm with a large capacity ($x \in X_3$), the flexible firm may earn more profit when demand is low, in which case the inflexible firm shuts down and the flexible one is a monopolist, than when demand is high, in which case the inflexible firm captures a large market share. It may therefore happen that the flexible firm avoids bankruptcy when the demand is low but goes bankrupt when the demand is high ! We do not study such cases.

The difference between the two profit levels is the expected bankruptcy cost. The different values of $\pi_1(\cdot)$, $D(\cdot)$ and $\widehat{E\Pi}(\cdot)$ are given in Appendix A.

3.2   Financial contract and expected profit of an inflexible firm

If either $x \in X_1 \cup X_3$ and $t' \in \{i, f\}$ or $x \in X_2$ and $t' = f$, the gross profit of an inflexible firm is equal to $\pi_1(i, t', X)$ which defines the debt threshold

$$D(i, t', X) = \pi_1(i, t', X) \tag{6}$$

If it has a debt lower than this gross profit, it never goes bankrupt and $R_h = K - A_h$. Otherwise it goes bankrupt and the zero expected payoff condition of the bank takes the form $\mu \pi_1(i, t', X) + (1 - \mu) R_h = K - A_h$, implying that:

$$R_h = \frac{1}{1 - \mu} \left[K - A_h - \mu \pi_1(i, t', X) \right]. \tag{7}$$

Its expected profit is therefore given by

$$E\Pi(i, t', X) = \begin{cases} \widehat{E\Pi}(i, t', X), & \text{if } K - A_h \le D(i, t', X) \\ \widehat{E\Pi}(i, t', X) - \mu B, & \text{if } K - A_h > D(i, t', X) \end{cases} \tag{8}$$

where

$$\widehat{E\Pi}(i, t', X) = \mu \pi_1(i, t', X) + (1 - \mu) \pi_2(i, t', X) - K. \tag{9}$$

If both firms are inflexible and $x \in X_2$, only one firm produces if demand is low. We assume that the producing firm is determined randomly with probability $1/2$. Hence we must define two debt thresholds in this case: $\hat{D}(i, i, X_2) = 0$ if the firm does not produce and $D(i, i, X_2) = \pi_1(i, i, X_2)$ if it produces. Each firm goes bankrupt with probability $1/2$ if $K - A_h < D(i, i, X_2)$ and with probability 1 if $K - A_h > D(i, i, X_2)$. The repayment amount R_h to be paid when $\alpha = \alpha_2$ is given in the former case by

$$R_h = \frac{1}{1 - \mu/2}(K - A_h) \tag{10}$$

and in the latter case by

$$R_h = \frac{1}{1 - \mu} \left[K - A_h - \frac{1}{2} \mu \pi_1(i, i, X_2) \right]. \tag{11}$$

Making use of (10) and (11), we obtain the expected profit, equal for both firms:

$$E\Pi\left(i, i, X_2\right) = \begin{cases} \widehat{E\Pi}\left(i, i, X_2\right), & \text{if } K - A_h \leq 0 \\[2mm] \widehat{E\Pi}\left(i, i, X_2\right) - \frac{1}{2}\mu B, & \text{if } 0 < K - A_h \leq D(i, i, X_2) \\[2mm] \widehat{E\Pi}\left(i, i, X_2\right) - \mu B, & \text{if } K - A_h > D(i, i, X_2) \end{cases} \qquad (12)$$

where

$$\widehat{E\Pi}\left(i, i, X_2\right) = \mu\frac{1}{2}\pi_1(i, i, X_2) + (1 - \mu)\,\pi_2(i, i, X_2) - K. \qquad (13)$$

4 The impact of equity on technological choices

A firm's cost of borrowing, expected profit and probability of bankruptcy are determined by the technological configuration of the industry and its own level of equity. Hence the technological best reply of a firm to the technological choice of its competitor depends on its own equity level. To characterize the impact of equity financing on the technological equilibrium in an industry, we must first study its impact on the technological best reply functions. We will illustrate our results with examples for each of the three cases of small, intermediate and large capacity of the inflexible technology.

A firm's debt level is given by the cost of the technology it chooses, either K or $K + H$, minus its equity A_h. For a given technological configuration, a firm's expected profit is a constant function of the debt level provided that the firm can make the repayment even when the demand is low; when debt is high, the expected net profit is reduced by the expected bankruptcy costs. Bankruptcy allows a standard debt contract to be an elegant and simple solution to the adverse selection problem raised by the unobservability of profit. Without that agency problem, the optimal financing contract would be a profit sharing contract under which the firm would never go bankrupt. If there is no bankruptcy cost, we find the well known Modigliani and Miller (1958) result: the capital structure of the firm is irrelevant, as shown by the best reply functions derived in Appendix B.

Proposition 4.1 *If there is no bankruptcy costs (B=0), the technological choices are independent of the firms' capital structure.*

With bankruptcy costs, the need to borrow may induce the firm to choose a different technology.

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4.1 The best response to inflexibility

Suppose that a firm chooses the inflexible technology. To determine the competitor's best response, we must determine the value of its expected profit differential $E\Pi(i,i,X) - E\Pi(f,i,X)$, for $X \in \{X_1, X_2, X_3\}$, which for each X is a step function of its equity. The qualitative characteristics of these functions turn out to be the same for X_1 and X_3 but differ for X_2.

4.1.1 The case $X \in \{X_1, X_3\}$

Let $A(i,i,X)$ and $A(f,i,X)$ be the minimum equity required for not going bankrupt in the low state of demand when choosing respectively the inflexible and the flexible technology, that is:

$$
\begin{aligned}
A(i,i,X) &= K - D(i,i,X) \\
A(f,i,X) &= K + H - D(f,i,X)
\end{aligned}
\tag{14}
$$

and so, $A(i,i,X) < A(f,i,X)$ iff $H > \pi_1(f,i,X) - \pi_1(i,i,X)$.

If a firm's equity is relatively low [large], the firm [never] goes bankrupt if demand is low whatever its technology. Hence the technological best response in these two cases will be the same and independent of the expected cost of bankruptcy μB. For intermediate levels of equity, that is a level between the critical levels (14), whether or not a firm goes bankrupt in the low state of demand will depend on its technology and therefore its best response will depend on the expected bankruptcy cost μB:

- If $A(i,i,X) < A(f,i,X)$ and if its equity falls between those two critical values, that is if $A(i,i,X) < A_h < A(f,i,X)$, the firm goes bankrupt in the low state of demand iff it has a flexible technology.

- If $A(f,i,X) < A(i,i,X)$ and if $A(f,i,X) < A_h < A(i,i,X)$, the firm goes bankrupt in the low state of demand iff it has an inflexible technology.

The formal characterization of a firm's technological best reply to the technological choice of its competitor is given in Appendix B. From (4) and (8), we obtain the following two propositions.

Proposition 4.2 (For $x \in X \in \{X_1, X_3\}$): *If $A(i,i,X) < A(f,i,X)$, a switch occurs in the technological best response to inflexibility as equity A_h increases iff $\widehat{E\Pi}(f,i,X) > \widehat{E\Pi}(i,i,X)$*

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(flexibility is the best response under no debt) and $\mu B > \widehat{E\Pi}(f, i, X) - \widehat{E\Pi}(i, i, X)$ (the expected cost of bankruptcy is sufficiently high). In such a case, the best response to inflexibility is flexibility for low levels of equity, inflexibility for intermediate levels of equity, flexibility for high levels of equity.

Proposition 4.3 (For $x \in X \in \{X_1, X_3\}$): *If $A(f, i, X) < A(i, i, X)$, a switch occurs in the best response to inflexibility as equity A_h increases iff $\widehat{E\Pi}(i, i, X) > \widehat{E\Pi}(f, i, X)$ (inflexibility is the best response under no debt) and $\mu B > \widehat{E\Pi}(i, i, X) - \widehat{E\Pi}(f, i, X)$ (the expected cost of bankruptcy is sufficiently high). In such a case, the best response to inflexibility is inflexibility for low levels of equity, flexibility for intermediate levels of equity, inflexibility for high levels of equity.*

4.1.2 The case $X = X_2$

For the intermediate capacity level of the inflexible technology, the analysis is a bit more complex. By choosing the inflexible technology, a firm facing an inflexible competitor will, if demand is low, either never go bankrupt if its equity is higher than K (it then has no debt), or goes bankrupt with probability $1/2$ if its equity is lower than K but higher than $A(i, i, X_2) = K - D(i, i, X_2)$, or always go bankrupt if its equity is lower than $A(i, i, X_2)$. If the firm chooses instead the flexible technology, the minimum level of equity necessary to avoid bankruptcy in the low state of demand is $A(f, i, X_2) = K + H - D(f, i, X_2)$. Since $A(i, i, X_2) < K$, we must now examine three possibilities depending on whether $A(f, i, X_2)$ is higher than K, between K and $A(i, i, X_2)$, or lower than $A(i, i, X_2)$. From (4), (8) and (12), we obtain the following two propositions.

Proposition 4.4 (For $x \in X_2$): *The technological best response to inflexibility goes from flexibility to inflexibility and to flexibility again as equity A_h increases, under two sets of conditions. First, when $K < A(f, i, X_2)$ iff $\widehat{E\Pi}(f, i, X_2) > \widehat{E\Pi}(i, i, X_2)$ and $\mu B > \widehat{E\Pi}(f, i, X_2) - \widehat{E\Pi}(i, i, X_2)$; second, when $A(i, i, X_2) < A(f, i, X_2) < K$ iff $\widehat{E\Pi}(f, i, X_2) > \widehat{E\Pi}(i, i, X_2)$ and $\mu B > 2 \left[\widehat{E\Pi}(f, i, X_2) - \widehat{E\Pi}(i, i, X_2) \right].$*[7]

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[7]In the first case, the levels of equity for which inflexibility is the best response are given by $A_h \in (A(i, i, X_2), A(f, i, X_2))$ or $A_h \in (K, A(f, i, X_2))$ according to whether $\widehat{E\Pi}(f, i, X_2) - \widehat{E\Pi}(i, i, X_2)$ is lower or higher than $\frac{1}{2}\mu B$.

Proposition 4.5 (For $x \in X_2$): *The technological best response to inflexibility goes from inflexibility to flexibility and to inflexibility again as equity A_h increases, under two sets of conditions. First, when $A(i,i,X_2) < A(f,i,X_2) < K$ iff $\widehat{E\Pi}(i,i,X_2) > \widehat{E\Pi}(f,i,X_2)$ and $\mu B > 2\left[\widehat{E\Pi}(i,i,X_2) - \widehat{E\Pi}(f,i,X_2)\right]$; second, when $A(f,i,X_2) < A(i,i,X_2) < K$ iff $\widehat{E\Pi}(i,i,X_2) > \widehat{E\Pi}(f,i,X_2)$ and $\mu B > \widehat{E\Pi}(i,i,X_2) - \widehat{E\Pi}(f,i,X_2)$.*[8]

4.2 The best response to flexibility

Let us define $A(i,f,X)$ and $A(f,f,X)$ for $X \in \{X_1, X_2, X_3\}$ as the minimum level of equity required to avoid bankruptcy when the firm chooses respectively the inflexible and the flexible technology whereas the other firm is a flexible firm, that is:

$$A(i,f,X) = K - D(i,f,X) \;\; ; \;\; A(f,f,X) = K + H - D(f,f,X). \tag{15}$$

An argument similar to the argument developed for characterizing the best response to inflexibility leads to the following propositions.

Proposition 4.6 (For $X \in \{X_1, X_2, X_3\}$): *When $A(i,f,X) < A(f,f,X)$, a switch occurs in the best response to flexibility as A_h increases iff $\widehat{E\Pi}(f,f,X) > \widehat{E\Pi}(i,f,X)$ and $\mu B > \widehat{E\Pi}(f,f,X) - \widehat{E\Pi}(i,f,X)$. In such a case, the best response to flexibility is flexibility for low levels of equity, inflexibility for intermediate levels, flexibility for high levels.*

Proposition 4.7 (For $X \in \{X_1, X_2, X_3\}$): *When $A(i,f,X) > A(f,f,X)$, a switch occurs in the best response to flexibility as A_h increases iff $\widehat{E\Pi}(i,f,X) > \widehat{E\Pi}(f,f,X)$ and $\mu B > \widehat{E\Pi}(i,f,X) - \widehat{E\Pi}(f,f,X)$. In such a case, the best response to flexibility is inflexibility for low levels of equity, flexibility for intermediate levels, inflexibility for high levels.*

4.3 Examples

The following examples show how the above best response functions generate equilibrium technological configurations in the industry as functions of the equity levels of the firms. The examples are worked out in Appendix C.

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[8]In the second case, the levels of equity for which flexibility is the best response are given by $A_h \in (A(f,i,X_2), K)$ or $A_h \in (A(f,i,X_2), A(i,i,X_2))$ according to whether $\widehat{E\Pi}(i,i,X_2) - \widehat{E\Pi}(f,i,X_2)$ is lower or higher than $\frac{1}{2}\mu B$.

Example 1: $x \in X_1$; $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 1$, $B = 2$. We consider first a common equity level for both firms, that is $A_h = A$ for $h = 1, 2$ (Figure 1), before looking at the more general case of asymmetric levels (Figure 1$'$).

<div align="center">

FIGURE 1 (example 1)

[in Y, (f, f) and (i, i)]

</div>
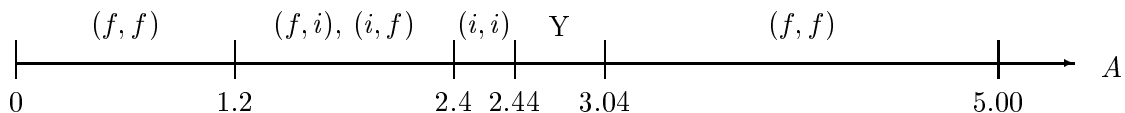
If the common equity level can cover the cost of both technologies ($A = 5$), both firms choose the flexible technology in equilibrium. If $2.44 < A < 3.04$, there are two Nash equilibria in which both firms choose the same technology, either the flexible or the inflexible one. For those equity levels, the firms fall into a flexibility trap, a coordination failure, as shown in Appendix C. If $2.4 < A < 2.44$, the unique equilibrium is (i, i). If $1.2 < A < 2.4$, the equilibrium is asymmetric, (f, i) or (i, f). Finally, if the common equity level is small ($A < 1.2$), the equilibrium is again (f, f).

When the equity levels are different, new cases appear (see Figure 1$'$).

<div align="center">

Insert Figure 1$'$ here

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There are values for which the unique equilibrium is asymmetric, (f, i) or (i, f). There are also two sets of values for which there exist no equilibrium in pure strategies. Within these sets, one firm's best reply is to mimic the technological choice of its rival while for the other, it is to choose a technology different from its rival's. One should notice that the technological choice of a firm is not a monotonic function of its equity level, given the equity level of its competitor: for example, if A_1 is in the interval $(0, 1.2)$, firm 2 chooses the flexible technology if its equity level is small, that is, if $A_2 \in (0, 1.2)$, the inflexible technology for intermediate equity levels, that is, for $A_2 \in (1.2, 2.44)$, and again the flexible technology if its equity level is large, that is, if $A_2 \in (2.44, 5)$. Also, the technological choice of a firm is not a monotonic function of the equity level of its competitor, given its own equity level: for example, if A_1 is

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in the interval (1.2, 2.4), firm 1 chooses the inflexible technology if its competitor's equity level is small, that is, if $A_2 \in (0, 1.2)$, the flexible technology for intermediate equity levels, that is, for $A_2 \in (2.4, 2.44)$, and again the inflexible technology if its competitor's equity level is large, that is, if $A_2 \in (3.04, 5)$.

When firms are totally financed by equity, they choose the flexible technology. This technology allows firms to take advantage of the opportunities offered when demand is high. Firms adopt the flexible technology in spite of its two disadvantages : a higher fixed cost and a lower profit when demand is low. If equity is reduced and borrowing necessary, a flexible firm may go bankrupt if the demand is low. It can eliminate this risk if it chooses the inflexible technology, allowing a reduction in the amount borrowed and an increase in profit when demand is low at the cost of a reduction in profit when demand is high. The expected value and variance of profit decrease. These effects explain the switch in equilibrium from (f, f) to (i, f) when the equity of firm 1 decreases.

But the technological switch of firm 1 may also make the flexible technology of the other firm more risky. When firm 1 becomes inflexible, the expected value and variance of profit for the flexible firm 2 increase. This may make the firm bankrupt if demand is low. By choosing an inflexible technology, the firm can reduce the variance of its profit. This explains the existence of two equilibria in zone Y of Figure 1 and of a unique equilibrium (i, i) in the hatched zone. When firms have very low equity, a change in technology is insufficient to eliminate the probability of bankruptcy. The previous effect disappears and firms choose again flexible technologies. Hence, when the capacity of the inflexible technology is low, the presence of debt favors flexible technologies because they are less risky, the variance of profit being lower.

This example is very instructive. It shows that the technological flexibility choices of the firms depend on their level of equity. Hence, on two perfectly identical markets, the technological configurations may differ if the firms have different access to equity financing. One cannot predict which technological configuration will emerge simply from observing demand and costs conditions.

Example 2: $x \in X_2$; $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2.5$, $\beta = 1$, $c = 0.2$, $K = 3$, $H = 0.5$, $B = 6$. Again, we consider first a common equity level for both firms, that is $A_h = A$ for $h = 1, 2$

(Figure 2), before looking at the more general case of asymmetric levels (Figure 2′).

FIGURE 2 (example 2)

[in Y, (f, f) and (i, i)]
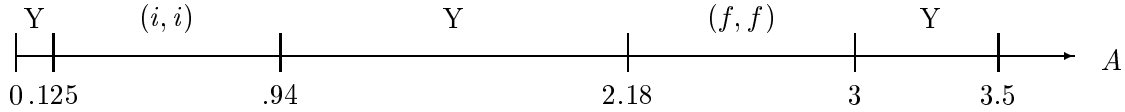
If both firms are all equity firms, there are two equilibria (f, f) and (i, i), so that the firms may fall into a flexibility trap since (i, i) would be more profitable for both of them. If the equity levels decrease but remain equal to each other, then (f, f) becomes the unique equilibrium. If equity decreases even more, we have again two equilibria (f, f) and (i, i) but, contrary to the first situation, profits are now higher in the (f, f) equilibrium. The firms may here fall into an inflexibility trap. A further decrease in equity levels brings (i, i) as the unique equilibrium. Last, if the firms have close to zero equity, there are again two equilibria (f, f) and (i, i) with the latter being more profitable for both firms.

When the equity levels differ, other equilibria appear (see Figure 2′).

Insert Figure 2′ here

There exist two sets of equity values for which the firms choose opposite technologies. There are also equity values for which (f, f) and (i, i) are equilibria but with no trap since none is uniformly better for both firms. Again, the observation of demand and cost conditions in an industry is not sufficient to predict which technological configuration will emerge. If the firms are totally financed by equity, there are two technological equilibrium configuration: (f, f) and (i, i). The existence of these two pure strategies equilibria may be explained by the strategic value of flexibility. Assume that the initial situation is (i, i). If a firm changes its technology and chooses flexibility, it will be able to adapt its output level to the demand level. It will decrease its production when the demand is low and increase it when the demand is high. This increases the firm's profit but not enough to cover the larger fixed cost of the flexible technology. But if the other firm is also flexible, then adoption of the flexible technology has strategic effects: the

firm commits herself in a credible way to an higher output level when demand is high. This commitment induces the other firm, also flexible, to decrease its output level when the demand is high. In this context, flexibility has a positive strategic value. When demand is low the opposite effect arises and flexibility has a negative strategic value. For the parameter values of example 2, the net strategic value of flexibility is positive. When a firm adopts the flexible technology, the value of flexibility increases for the other firm as well. This effect explains the existence of the two pure strategy equilibria.[9]

If one firm has initially less equity, it must borrow and may end up bankrupt (with probability $1/2$) if the demand is low when the technological configuration is (i, i). By switching to flexibility, the firm already in debt must borrow additional funds to finance the higher fixed cost of the flexible technology. But its increase in profit when demand is low is more important and eliminates the risk of bankruptcy. When the firm in debt changes its technology, the other firm is induced to change its technology too: there is a unique equilibrium technological configuration (f, f).

Hence, when the capacity of the inflexible technology is intermediate, the equilibrium technological configuration can evolve toward more flexibility or more inflexibility as leverage increases because the level of risk linked to a technology depends on the technology chosen by the other firm.

Example 3: $x \in X_3$; $\mu = 0.1$, $\alpha_1 = 4$, $\alpha_2 = 15$, $x = 5$, $\beta = 1, c = 0.2$, $K = 4$, $H = 0.5$, $B = 6$. The common equity level case is illustrated in Figure 3 and the more general case of asymmetric levels in Figure 3$'$.

FIGURE 3 (example 3)
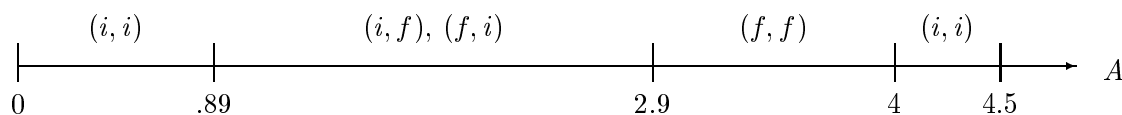
As in the preceding two examples, the equilibrium technological configuration is changing with the equity levels. When the levels of equity are the same for both firms, $A_h = A$, $h = 1, 2$, the

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[9]For more on the strategic value of technological choices, see Boyer, Jacques and Moreaux (2000).

firms both choose the inflexible technology if they have a relatively large level of equity, $A > 4$. For intermediate equity levels, $2.9 < A < 4$, they both switch to the flexible technology. For lower equity levels, $0.89 < A < 2.9$, they choose different technologies and for even lower equity levels, $A < 0.89$, they both come back to the inflexible technology. The case of asymmetric equity positions is illustrated in Figure $3'$.

In this example, the capacity of the inflexible technology is so high that a firm using this technology always shuts down when the demand is low. As a result, the probability of bankruptcy of an inflexible firm is strictly positive as soon as its debt is strictly positive. A leveraged firm then prefer to switch to a flexible technology, thereby eliminating the risk of bankruptcy. When the firm's debt is larger, choosing a flexible technology eliminates the risk of bankruptcy if the other firm is inflexible but not if the other firm is flexible. Therefore in equilibrium, one firm switches to the flexible technology to eliminate its risk of bankruptcy while the other keeps an inflexible technology and a positive probability of bankruptcy. If equity levels are very low, the real option value of flexibility disappears and the firms end up in a (i, i) equilibrium as when equity is very large.

We can conclude this section 4 by saying that the impact of equity financing on the technological configuration of an industry is, as illustrated in examples 1 to 5, a rather subtle non monotonous impact combining decision theoretic effects, real option effects and strategic effects.

5   The strategic value of equity

The fact that the level of equity, assumed to be exogenous till now, can change the technological best reply functions suggests that the level of equity could be chosen strategically. Note however that the best responses are functions of both the equity level and the bankruptcy cost which are substitute commitment devices. Hence it is the pair $(A_h, \ B)$ which has a strategic value. In order to appreciate the competitive potential of an industry, we have to look at what could be called the industry 'commitment index', a function of both the equity financing and the bankruptcy cost.

5.1 Equity financing as a commitment device

In the previous section we assumed that A_h, the capital invested in his business by entrepreneur h, was his given initial wealth and that because of the agency problem, the entrepreneur could not raise additional funds through external equity. We relax that assumption in this section. We will assume that the entrepreneur's initial wealth is larger than $K + H$ but that in a preliminary stage 0, the two entrepreneurs choose simultaneously the amounts A_h they will invest in their respective firms. If the invested capital is lower than the cost of the chosen technology, the firm must borrow. We show next that there exist cases in which the entrepreneurs decide to finance their firms in part through borrowing in order to modify in a credible way their technological reaction functions.

Let us examine again example 1 (Figure $1'$). If the firms are whole equity firms, the technological equilibrium is (f, f). Each firm's expected profit is then equal to 1.62 even if in the technological configuration (i, i), their common expected profit would be higher at 2.6 (See Appendix C). When the firms are all equity financed, they play a prisoner dilemma game. If they decrease their equity capital, they alter the payoff matrix and they avoid the dilemma. In example 1, if both firms have an equity capital of $A = 3$, they play a subgame admitting (f, f) and (i, i) as equilibria and they never go bankrupt. For even lower equity capital, the firms can reach the unique equilibrium configuration (i, i) which is better for them than (f, f). By reducing their equity capital, the firms credibly commit not to reply to inflexibility by flexibility. When the rival is inflexible, a flexible firm earns a high profit level when demand is high but a low profit level when demand is low. Hence, if the firm must borrow a large amount to buy the flexible technology, it goes bankrupt when demand is low. The expected bankruptcy cost makes flexibility less attractive than inflexibility when the other firm is inflexible. When the best reply to inflexibility switches from flexibility to inflexibility, the firms avoid the prisoner dilemma and play a coordination game. Therefore firms can both increase their expected profits by choosing strategically their capital structure:[10] debt has a strategic value in this context.

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[10]The firms would be better off eliminating the configuration (f, f) as an equilibrium by reducing even more their equity capital but such capital structures are not equilibria of the preliminary stage reduced form game: a firm would be better off deviating and increasing its equity capital to $A_h = 4$ to induce the configuration (f, i) as the unique equilibrium. If firms were choosing their capital structure sequentially, a form of coordination among firms, they would avoid this problem. The leader would then choose $A_1 = 3$ and the follower $A_2 = 2.42$ with

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In example 2 (Figure $2'$), the best technological configuration for the firms is (i, i) with financing mainly through equity $A_h > 3$. This equilibrium (i, i) is not unique and there is a flexibility trap here. A lower level of equity would eliminate this trap but one of the two firms would then go bankrupt when demand is low. The bankruptcy cost makes this strategy unattractive. So the firms will choose not to borrow. However debt may have a strategic value as in the following example 4: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 4$, $\beta = 1$, $c = 0.2$, $K = 2.5$, $H = 0.1$ and $B = 3$, with its equilibrium technological configurations depicted in Figure 4. If the firms are all equity firms, the unique equilibrium is (i, i), even if firms would earn greater profits in the technological configuration (f, f), hence an inflexibility trap here. If the firms cut down their equity capital to $A_h = 2.45$, the equilibrium of the following subgame becomes (f, i) or (i, f) and the sum of profits increases. But these equity levels are not an equilibrium of the preliminary stage game. A firm would deviate to be an all equity firm. On the other hand, firms can increase their expected profits by cutting down sharply their equity capital to say $A_h = 0.8$; the subgame then admits two equilibria (f, f) and (i, i). In the latter equilibrium, one firm goes bankrupt when demand is low. In the former one, firms never go bankrupt. If the two equilibria have the same probability, the expected payoff of firms increases. Furthermore, these are equilibrium capital structures. Debt can again increase the expected profits of both firms.

Insert Figure 4 here

Last, let us consider the following example 5 for the case of a large capacity level of the inflexible technology, $x \in X_3$: $\mu = 0.3$, $\alpha_1 = 5$, $\alpha_2 = 18$, $x = 6$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.75$ and $B = 3$, with its equilibrium technological configurations depicted in Figure 5. In this example one firm chooses to be an all equity firm with the inflexible technology and the other firm chooses $A_h \in (2.2,\ 4)$ together with the flexible technology. The more profitable firm is the flexible firm. Debt allows the firm to select the most profitable technology. In example 3 ($x \in X_3$), the capital structure could be used strategically to increase the expected profits of both firms. In example 5 ($x \in X_3$), the capital structure is used strategically by one firm to increase its expected profit at the expense of the other.[11]

the unique technological equilibrium being (i, i). In this configuration, the firms never go bankrupt. So raising borrowed capital has no cost.

[11]The strategic commitment value of issuing debt is emphasized when the firms choose their technologies

Insert Figure 5 here

Clearly, whatever the capacity level of the inflexible technology, there exist subsets of parameter values for which the equilibrium capital structures combine equity and debt. In these equilibria, the debt is used strategically to modify the equilibrium technological configuration of the industry which would have emerged had the entrepreneurs decided to finance their firms through equity only.

5.2 The strategic increase of bankruptcy costs

We showed above that the capital structure can be used strategically in order to influence the technological choice of the rival when the bankruptcy costs are high enough to change the technological best reply functions (propositions 4.2 to 4.7). A reduction in bankruptcy costs would no more allow this strategic use of the capital structure and therefore may indeed decrease the expected profits of the firms. In these cases, the firms could try to artificially increase the bankruptcy costs. A simple way to do that is, for entrepreneurs, to offer judiciously chosen assets as collateral for their debt or induce banks to ask for those collateral assets.[12]

The bank and the entrepreneur may have different evaluations of the collateral assets, some assets having a greater value for the debtor than for the creditor. In general, this difference is inefficient and the contracting parties have an interest to choose the assets with the lowest evaluation difference. However Williamson (1983, 1985) argues that in some contracts, it may be better that the collateral assets have a low value for the creditor. This can prevent a cancellation of the contract aimed at seizing the collateral assets. Our analysis proposes another explanation for this kind of behavior. Increasing the difference of evaluation increases the bankruptcy cost and so increases the commitment power of debt.[13]

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sequentially. If the two firms are all equity firms, the leader chooses flexibility and the follower chooses inflexibility with payoffs of 21.35 and 20.78 respectively. However, by choosing $A_2 = 3$, the follower changes its best reply to flexibility in the following stage. If the leader chooses flexibility, the follower then chooses flexibility too with payoff of 20.66 for both. The leader then prefers inflexibility and the follower chooses flexibility with payoffs of 20.78 and 21.35 respectively. The follower, by issuing debt, can outperform the leader in terms of profit. There is another perfect equilibrium in which the leader chooses $A_h \in (2.2, 4)$ with the flexible technology and the follower is an all equity firm with the inflexible technology; but, in the first stage, the leader plays a weakly dominated strategy. See Ellingsen (1995) for an analysis of games with a similar structure although in a different context.

[12]See Freixas and Rochet (1997, chapters 4 and 5) for references.

[13]We find in Shakespeare, *The merchant of Venice* $[I, 3]$, an extreme example of this type of debt contract:

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Another way to increase the bankruptcy costs is to delegate the investment decision to a manager to be fired in case of bankruptcy. If the control of the firm gives to the manager enough private benefits, then the manager will choose the technology which minimize the firm's bankruptcy probability. In order to increase the bankruptcy costs and give them strategic value, shareholders can provide more private benefits to the manager.

6 Conclusion

The bankruptcy costs and the equity levels of firms have significant impacts on the equilibrium technological configurations in an industry. These effects arise because indebted firms, either flexible or inflexible, may want to change their technologies to reduce the probability of bankruptcy. When the capacity level associated with the inflexible technology is low, the equilibrium technological configuration of the industry is more inflexible if firms have moderate levels of equity than if they are whole equity firms (Figure 1). When that capacity level is large, moderate levels of equity make the technological configuration of the industry more flexible (Figure 3). The effect of equity is not monotonous. An industry may have the same technological equilibrium for low and high levels of debt, with a different equilibrium for intermediate levels of debt.

The endogeneity of technological choices is likely to be an important determinant of the optimal capital structure and of the relationship between capital structure and product market competition. Our results allow us to take some steps in characterizing the role of endogenous technological flexibility choices, whose analysis has been neglected in the literature.

"*Shylock*:
    This kindness will I show.
    Go with me to a notary, seal me there
    Your single bond, and, in a merry sport,
    If you repay me not on such a day,
    In such a place, such a sum or sums as are
    Expressed in the condition, let the forfeit
    Be nominated for an equal pound
    Of your fair flesh, to be cut off and taken
    In what part of your body pleaseth me.
Antonio:
    Content, in faith - I'll seal to such a bond,
    And say there is much kindness in the Jew."

The main determinants of capital structure, as modeled and identified in the literature, can be regrouped under four major headings: taxation, information asymmetries together with conflicts of interest, competitive positioning and finally corporate control.[14] If the interest payments are tax-deductible while dividends are not, debt has an advantage over equity. Conflicts between shareholders and managers may arise because managers, when owning only a small percentage of shares, may end up exerting a suboptimal level of effort and investing the free cash flows in perks and acquisitions of low value (Jensen and Meckling 1976, Jensen 1986). Conflicts between shareholders and debtholders arise because the payoff of shareholders [debtholders] is a convex [concave] function of the firm's profit: the shareholders prefer riskier projects (Jensen and Meckling 1976). Information asymmetries between managers and outside investors on the profitability of the firm is a third determinant whose importance decreases as the firm carries more debt because the evaluation of the firm's debt is less sensitive to specific informations (Myers and Majluf 1984) and the expected bankruptcy costs increase faster for a firm with low profitability (Ross 1977). A firm's capital structure may also modify its own behavior and the behavior of its competitors on product markets: managers take more risk or may be more cooperative when the firm carries debt and therefore debt can be used as a credible commitment to increase the level of output (Brander and Lewis 1986) or to set higher prices (Showalter 1995). Finally, the firm's capital structure may modify the probability of a successful takeover by an outside investor. In order to determine the optimal combination between debt and equity, firms must consider simultaneously these determinants. The significance of each determinant depends on the specific environment of the firm.

Our analysis emphasizes the strategic effects of capital structure through not only a marginal change in product quantity or price but also in far reaching technology changes[15] modifying the organization and the market strategy of the firm. This determinant is likely to be even more important than the other ones in part because other less costly means may be available to achieve the objectives behind the other determinants. For instance, conflicts between stakeholders can be soften by more sophisticated managerial contracts and the likelihood of a hostile takeover

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[14]See for instance the recent contributions of Harris and Raviv (1991), Hart (1995), Rajan and Zingales (1995), Leland and Toft (1996).

[15]Fazzari, Hubbard and Petersen (1988), Kaplan and Zingales (1997) and Cleary (1999) among others study the impact of capital structure on the level of investment in firms but they do not consider the different specific technologies acquired through these investments.

can be reduced by a strategic allocation of voting rights. For some market contexts or industry parameters, debt has a strategic value and increases a firm's expected profit (see examples 1, 3 and 4 above) but in other contexts debt is a source of weakness for the firm and decreases its expected profit. Example 2 illustrates this last point. In this example, debt can solve the coordination problem due to multiple equilibrium technological configurations but may lead to the selection of a Pareto-dominated equilibrium.

According to Brander and Lewis (1986), the output level increases with the debt level whereas in Glazer (1994), the output level decreases in the first period and increases in the second period as debt increases. In Showalter (1995), higher debt induces lower prices, that is higher output levels, when costs are uncertain, while the opposite effect holds when demand is uncertain. In our model, the link between debt levels and output levels is more subtle since debt not only induces changes in output and prices given the technologies but also changes in the technologies themselves. In example 1 above, a switch from (f, f) to (i, i) increases output if demand is low but decreases output if demand is high. In example 2, the same switch decreases output in the two states of demand.

It is nevertheless possible to draw some general results. If the market size is high relative to the capacity of the inflexible technology, debt favors inflexible equilibrium technological configurations resulting in less variability in industry output but more variability in prices. If the market size is small relative to the capacity of the inflexible technology, opposite effects emerge. In the intermediate case, both situations are possible depending on the industry parameters. Therefore, the effects characterized by Brander and Lewis (1986), Glazer (1994) and Showalter (1995) depend closely on the assumption that a single technology is available. If firms are allowed to choose between different flexibility levels, technological or organizational, the impacts of debt become much more subtle.

A   Cournot equilibria, debt thresholds and expected profits

By assumption, the state of demand is observed before the second stage Cournot competition takes place. For a state of the market α, the Cournot reaction function of a flexible firm h is $q_h = \frac{1}{2}\left((\alpha - c)/\beta - q_j\right),\ j \neq h$.

For $x \in X_1$ (equivalently α_1 sufficiently high), that is $x < (\alpha_1 - c)/2\beta$, both firms are always better off producing than not and we get:

- if both firms are flexible, the production level of each firm is $(\alpha_k - c)/3\beta$ and
  $\pi_k(f, f, X_1) = (\alpha_k - c)^2/9\beta$ with $D(f, f, X_1) = \pi_1(f, f, X_1) = (\alpha_1 - c)^2/9\beta$;
  the expected profit of each firm is given by (4) with
  $$\widehat{E\Pi}(f, f, X_1) = \frac{1}{9\beta}\left[\mu\left(\alpha_1 - c\right)^2 + (1 - \mu)\left(\alpha_2 - c\right)^2\right] - (K + H)$$

- if one firm is flexible and the other is inflexible, the production level of the flexible [inflexible]firm is $\frac{1}{2}\left((\alpha_k - c)/\beta - x\right)\ [x]$; we have $\pi_k(f, i, X_1) = (\alpha_k - c - \beta x)^2/4\beta$,
  $\pi_k(i, f, X_1) = \frac{1}{2}(\alpha_k - c - \beta x)x$ with $D(f, i, X_1) = \pi_1(f, i, X_1),\ D(i, f, X_1) = \pi_1(i, f, X_1)$;
  the expected profit of the flexible [inflexible] firm is given by (4) [(8)] with
  $$\widehat{E\Pi}(f, i, X_1) = \frac{1}{4\beta}\left[\mu\left(\alpha_1 - c - \beta x\right)^2 + (1 - \mu)\left(\alpha_2 - c - \beta x\right)^2\right] - (K + H),$$
  $$\widehat{E\Pi}(i, f, X_1) = \frac{1}{2}\left[\mu\alpha_1 + (1 - \mu)\alpha_2 - c - \beta x\right]x - K$$

- if both firms are inflexible, the production level of each firm is x; we have
  $\pi_k(i, i, X_1) = (\alpha_k - c - 2\beta x)x$ with $D(i, i, X_1) = \pi_1(i, i, X_1)$;
  the expected profit of each firm is given by (8) with
  $$\widehat{E\Pi}(i, i, X_1) = \left[\mu\alpha_1 + (1 - \mu)\alpha_2 - c - 2\beta x\right]x - K$$

For $x \in X_2$, that is $(\alpha_1 - c)/2\beta < x < (\alpha_1 - c)/\beta$, we get:

- for (f, f) and (f, i), the equilibria are the same as in the case $x \in X_1$ above

- for (i, i), if demand is low, one firm shuts down $(D(i, i, X_2) = 0)$ and the other enjoys a monopoly position, that is $\pi_k(i, i, X_2) = (\alpha_k - c - \beta x)x$ with $D(i, i, X_2) = \pi_1(i, i, X_2)$;

the expected profit of both firms is given by (12) with

$$\widehat{E\Pi}(i,i,X_2) = \mu\frac{1}{2}\left(\alpha_1 - c - \beta x\right)x + (1-\mu)\left(\alpha_2 - c - 2\beta x\right)x - K.$$

For $x \in X_3$, that is $(\alpha_1 - c)/\beta < x$, we get:

- for (f,f), the equilibrium is the same as in the case where $x \in X_1$

- for (f,i), the inflexible firm shuts down when demand is low $(D(i,f,X_3) = 0)$ whereas the flexible firm enjoys a monopoly position, that is $\pi_k(f,i,X_3) = (\alpha_k - c)^2/4\beta$ and $D(f,i,X_3) = \pi_1(f,i,X_3)$;

  the expected profit of the firms are given by (4) and (8) with
  $$\widehat{E\Pi}(f,i,X_3) = \frac{1}{4\beta}\left[\mu\left(\alpha_1 - c\right)^2 + (1-\mu)\left(\alpha_2 - c - \beta x\right)^2\right] - (K+H),$$
  $$\widehat{E\Pi}(i,f,X_3) = \frac{1}{2}\left(1-\mu\right)\left(\alpha_2 - c - \beta x\right)x - K$$

- for (i,i), both firms shut down when demand is low and $D(i,i,X_3) = 0$;

  the expected profit of each firm is given by (8) with
  $$\widehat{E\Pi}(i,i,X_3) = (1-\mu)\left(\alpha_2 - c - 2\beta x\right)x - K.$$

B Technological best response

Best reply to inflexibility for $x \in X \in \{X_1, X_3\}$ **:**   inflexibility is the best response to inflexibility

- when $A(i,i,X) < A(f,i,X)$ iff:
$$\widehat{E\Pi}(i,i,X) - \mu B \ \geq \ \widehat{E\Pi}(f,i,X) - \mu B, \quad \text{for } A_h < A(i,i,X)$$

$$\widehat{E\Pi}(i,i,X) \ \geq \ \widehat{E\Pi}(f,i,X) - \mu B, \quad \text{for } A(i,i,X) < A_h < A(f,i,X)$$

$$\widehat{E\Pi}(i,i,X) \ \geq \ \widehat{E\Pi}(f,i,X), \qquad \text{for } A(f,i,X) < A_h$$

- when $A(f,i,X) < A(i,i,X)$ iff:
$$\widehat{E\Pi}(i,i,X) - \mu B \ \geq \ \widehat{E\Pi}(f,i,X) - \mu B, \quad \text{for } A_h < A(f,i,X)$$

$$\widehat{E\Pi}(i,i,X) - \mu B \ \geq \ \widehat{E\Pi}(f,i,X), \qquad \text{for } A(f,i,X) < A_h < A(i,i,X)$$

$$\widehat{E\Pi}(i,i,X) \ \geq \ \widehat{E\Pi}(f,i,X), \qquad \text{for } A(i,i,X) < A_h.$$

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Best reply to inflexibility for $x \in X_2$ **:**   inflexibility is the best reply to inflexibility

- when $A(i,i,X_2) < K < A(f,i,X_2)$ iff:

$$\widehat{E\Pi}(i,i,X_2) - \mu B \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } A_h < A(i,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) - \tfrac{1}{2}\mu B \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } A(i,i,X_2) < A_h < K$$

$$\widehat{E\Pi}(i,i,X_2) \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } K < A_h < A(f,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } A(f,i,X_2) < A_h$$

- when $A(i,i,X_2) < A(f,i,X_2) < K$ iff:

$$\widehat{E\Pi}(i,i,X_2) - \mu B \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } A_h < A(i,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) - \tfrac{1}{2}\mu B \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } A(i,i,X_2) < A_h < A(f,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) - \tfrac{1}{2}\mu B \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } A(f,i,X_2) < A_h < K$$

$$\widehat{E\Pi}(i,i,X_2) \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } K < A_h$$

- When $A(f,i,X_2) < A(i,i,X_2) < K$ iff:

$$\widehat{E\Pi}(i,i,X_2) - \mu B \quad > \quad \widehat{E\Pi}(f,i,X_2) - \mu B, \quad \text{for } A_h < A(f,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) - \mu B \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } A(f,i,X_2) < A_h < A(i,i,X_2)$$

$$\widehat{E\Pi}(i,i,X_2) - \tfrac{1}{2}\mu B \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } A(i,i,X_2) < A_h < K$$

$$\widehat{E\Pi}(i,i,X_2) \quad > \quad \widehat{E\Pi}(f,i,X_2), \quad \text{for } K < A_h$$

C Examples used in the text

Example 1: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 1$ and $B = 2$.

Profit levels:

$$
\begin{array}{rllcllcll}
3.04 \leq A_h & E\Pi\,(f,f) & = & 1.62 & > & E\Pi\,(i,f) & = & 1.30 \\
& E\Pi\,(f,i) & = & 3.59 & > & E\Pi\,(i,i) & = & 2.60 \\
2.44 \leq A_h < 3.04 & E\Pi\,(f,f) & = & 1.62 & > & E\Pi\,(i,f) & = & 1.30 \\
& E\Pi\,(f,i) & = & 2.59 & < & E\Pi\,(i,i) & = & 2.60 \\
2.4 \leq A_h < 2.44 & E\Pi\,(f,f) & = & 0.62 & < & E\Pi\,(i,f) & = & 1.30 \\
& E\Pi\,(f,i) & = & 2.59 & < & E\Pi\,(i,i) & = & 2.60 \\
1.2 \leq A_h < 2.4 & E\Pi\,(f,f) & = & 0.62 & < & E\Pi\,(i,f) & = & 1.30 \\
& E\Pi\,(f,i) & = & 2.59 & > & E\Pi\,(i,i) & = & 1.60 \\
A_h < 1.2 & E\Pi\,(f,f) & = & 0.62 & > & E\Pi\,(i,f) & = & 0.30 \\
& E\Pi\,(f,i) & = & 2.59 & > & E\Pi\,(i,i) & = & 1.60 \\
\end{array}
$$

Example 2: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2.5$, $\beta = 1$, $c = 0.2$, $K = 3$, $H = 0.5$ and $B = 6$.

Profit levels:

$$
\begin{array}{rllcllcll}
3 \leq A_h & E\Pi\,(f,f) & = & 3.11 & > & E\Pi\,(i,f) & = & 3.00 \\
& E\Pi\,(f,i) & = & 3.82 & < & E\Pi\,(i,i) & = & 4.44 \\
2.18 \leq A_h < 3 & E\Pi\,(f,f) & = & 3.11 & > & E\Pi\,(i,f) & = & 3.00 \\
& E\Pi\,(f,i) & = & 3.82 & > & E\Pi\,(i,i) & = & 2.94 \\
0.94 \leq A_h < 2.18 & E\Pi\,(f,f) & = & 3.11 & > & E\Pi\,(i,f) & = & 3.00 \\
& E\Pi\,(f,i) & = & 0.82 & < & E\Pi\,(i,i) & = & 2.94 \\
0.125 \leq A_h < 0.94 & E\Pi\,(f,f) & = & 0.11 & < & E\Pi\,(i,f) & = & 3.00 \\
& E\Pi\,(f,i) & = & 0.82 & < & E\Pi\,(i,i) & = & 2.94 \\
A_h < 0.125 & E\Pi\,(f,f) & = & 0.11 & > & E\Pi\,(i,f) & = & 0.00 \\
& E\Pi\,(f,i) & = & 0.82 & < & E\Pi\,(i,i) & = & 2.94 \\
\end{array}
$$

Example 3: $\mu = 0.1$, $\alpha_1 = 4$, $\alpha_2 = 15$, $x = 5$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.5$ and $B = 6$.

Profit levels:

$$
\begin{array}{llrlllr}
4 \leq A_h & E\Pi\left(f,f\right) & = & 17.56 & < & E\Pi\left(i,f\right) & = & 18.05 \\
 & E\Pi\left(f,i\right) & = & 17.47 & < & E\Pi\left(i,i\right) & = & 17.60 \\
2.9 \leq A_h < 4 & E\Pi\left(f,f\right) & = & 17.56 & > & E\Pi\left(i,f\right) & = & 17.45 \\
 & E\Pi\left(f,i\right) & = & 17.47 & > & E\Pi\left(i,i\right) & = & 17.00 \\
0.89 \leq A_h < 2.9 & E\Pi\left(f,f\right) & = & 16.96 & < & E\Pi\left(i,f\right) & = & 17.45 \\
 & E\Pi\left(f,i\right) & = & 17.47 & > & E\Pi\left(i,i\right) & = & 17.00 \\
A_h < 0.89 & E\Pi\left(f,f\right) & = & 16.96 & < & E\Pi\left(i,f\right) & = & 17.45 \\
 & E\Pi\left(f,i\right) & = & 16.87 & < & E\Pi\left(i,i\right) & = & 17.00
\end{array}
$$

Example 4: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 4$, $\beta = 1$, $c = 0.2$, $K = 2.5$, $H = 0.1$ and $B = 3$.

Profit levels:

$$
\begin{array}{llrlllr}
2.5 \leq A_h & E\Pi\left(f,f\right) & = & 4.02 & < & E\Pi\left(i,f\right) & = & 4.10 \\
 & E\Pi\left(f,i\right) & = & 1.69 & < & E\Pi\left(i,i\right) & = & 1.90 \\
2.44 \leq A_h < 2.5 & E\Pi\left(f,f\right) & = & 4.02 & < & E\Pi\left(i,f\right) & = & 4.10 \\
 & E\Pi\left(f,i\right) & = & 1.69 & > & E\Pi\left(i,i\right) & = & 1.15 \\
0.9 \leq A_h < 2.44 & E\Pi\left(f,f\right) & = & 4.02 & < & E\Pi\left(i,f\right) & = & 4.10 \\
 & E\Pi\left(f,i\right) & = & 0.19 & < & E\Pi\left(i,i\right) & = & 1.15 \\
0.04 \leq A_h < 0.9 & E\Pi\left(f,f\right) & = & 4.02 & > & E\Pi\left(i,f\right) & = & 2.60 \\
 & E\Pi\left(f,i\right) & = & 0.82 & < & E\Pi\left(i,i\right) & = & 1.15 \\
A_h < 0.04 & E\Pi\left(f,f\right) & = & 2.51 & < & E\Pi\left(i,f\right) & = & 2.60 \\
 & E\Pi\left(f,i\right) & = & 0.82 & < & E\Pi\left(i,i\right) & = & 1.15
\end{array}
$$

Example 5: $\mu = 0.3$, $\alpha_1 = 5$, $\alpha_2 = 18$, $x = 6$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.75$ and $B = 3$.

Profit levels:

$$
\begin{array}{llrlllr}
4 \leq A_h & E\Pi\left(f,f\right) & = & 20.66 & < & E\Pi\left(i,f\right) & = & 20.78 \\
 & E\Pi\left(f,i\right) & = & 21.35 & > & E\Pi\left(i,i\right) & = & 20.36 \\
2.19 \leq A_h < 4 & E\Pi\left(f,f\right) & = & 20.66 & > & E\Pi\left(i,f\right) & = & 19.88 \\
 & E\Pi\left(f,i\right) & = & 21.35 & > & E\Pi\left(i,i\right) & = & 19.46 \\
A_h < 2.19 & E\Pi\left(f,f\right) & = & 19.76 & < & E\Pi\left(i,f\right) & = & 19.88 \\
 & E\Pi\left(f,i\right) & = & 21.35 & > & E\Pi\left(i,i\right) & = & 19.46
\end{array}
$$

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FIGURE $1'$

Equilibrium technological configurations in example 1, $x \in X_1$;

in hatched zone, (i, i);

in Y, either (f, f) or (i, i);

in V, (f, i) or (i, f);
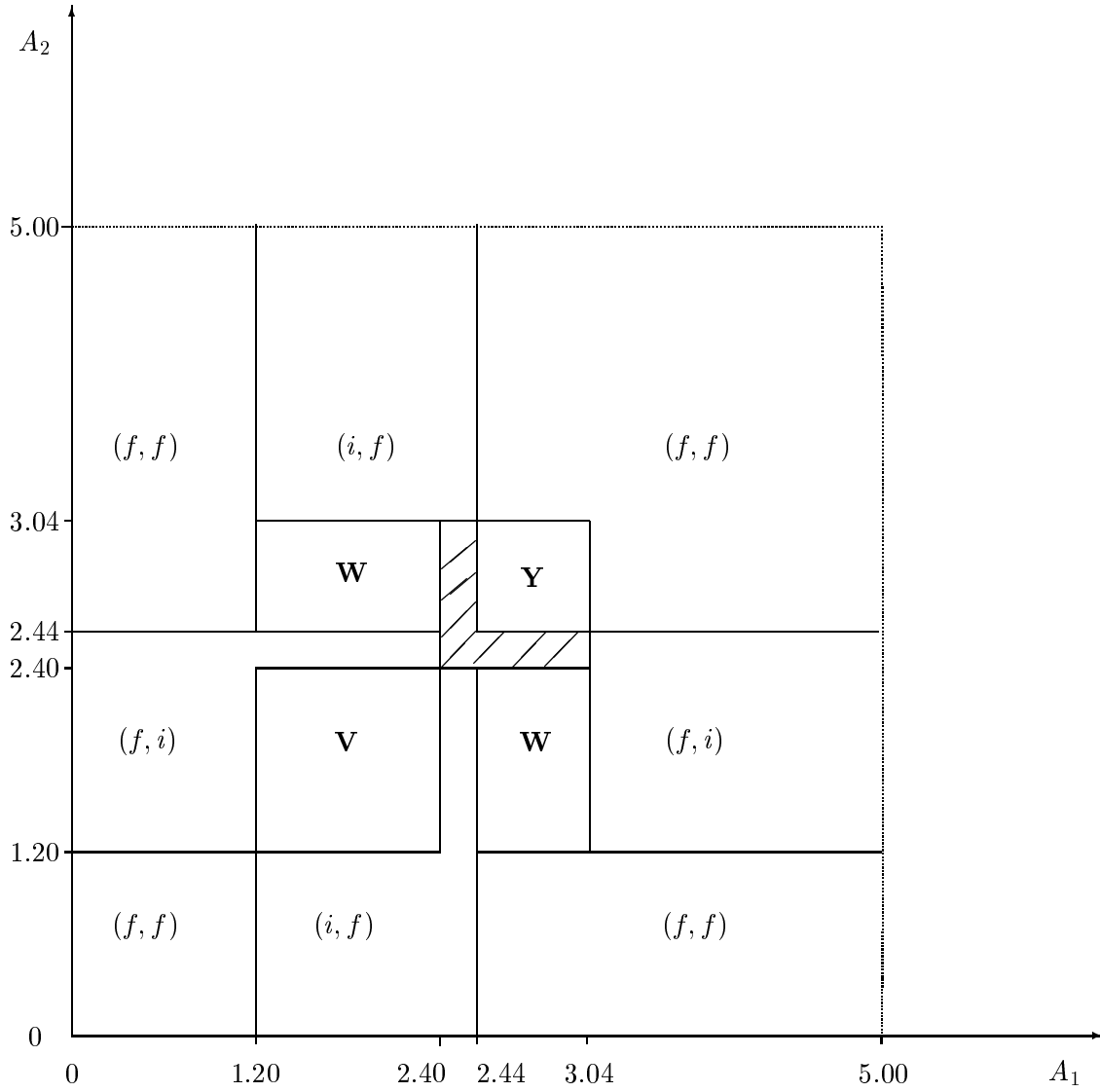
in W, no equilibrium in pure strategies.

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Figure $2'$

Equilibrium technological configurations in example 2, $x \in X_2$;
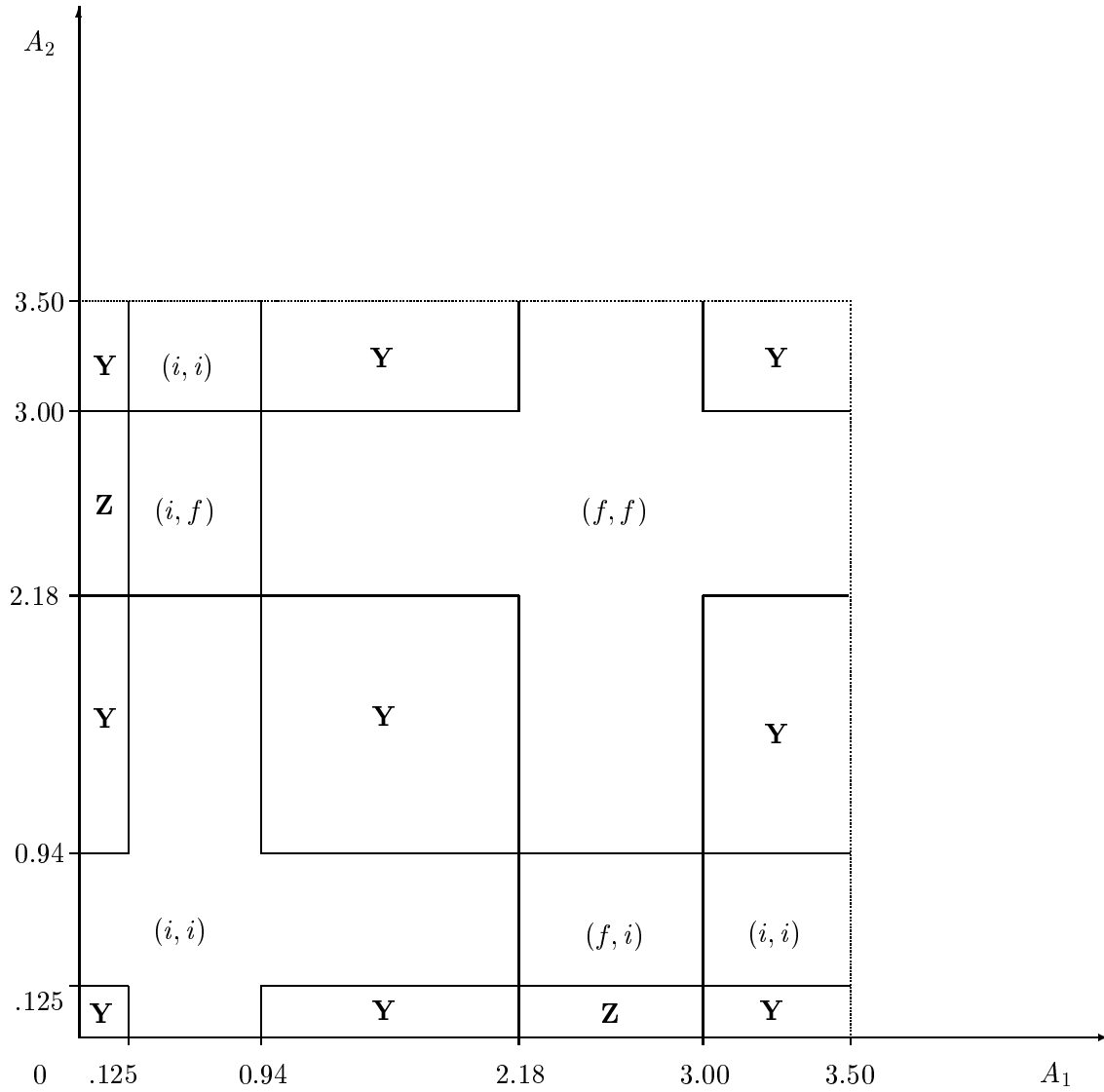
in Y, either (f,f) or (i,i);

in Z, (f,f).

FIGURE 3′

Equilibrium technological configurations in example 3, $x \in X_3$;
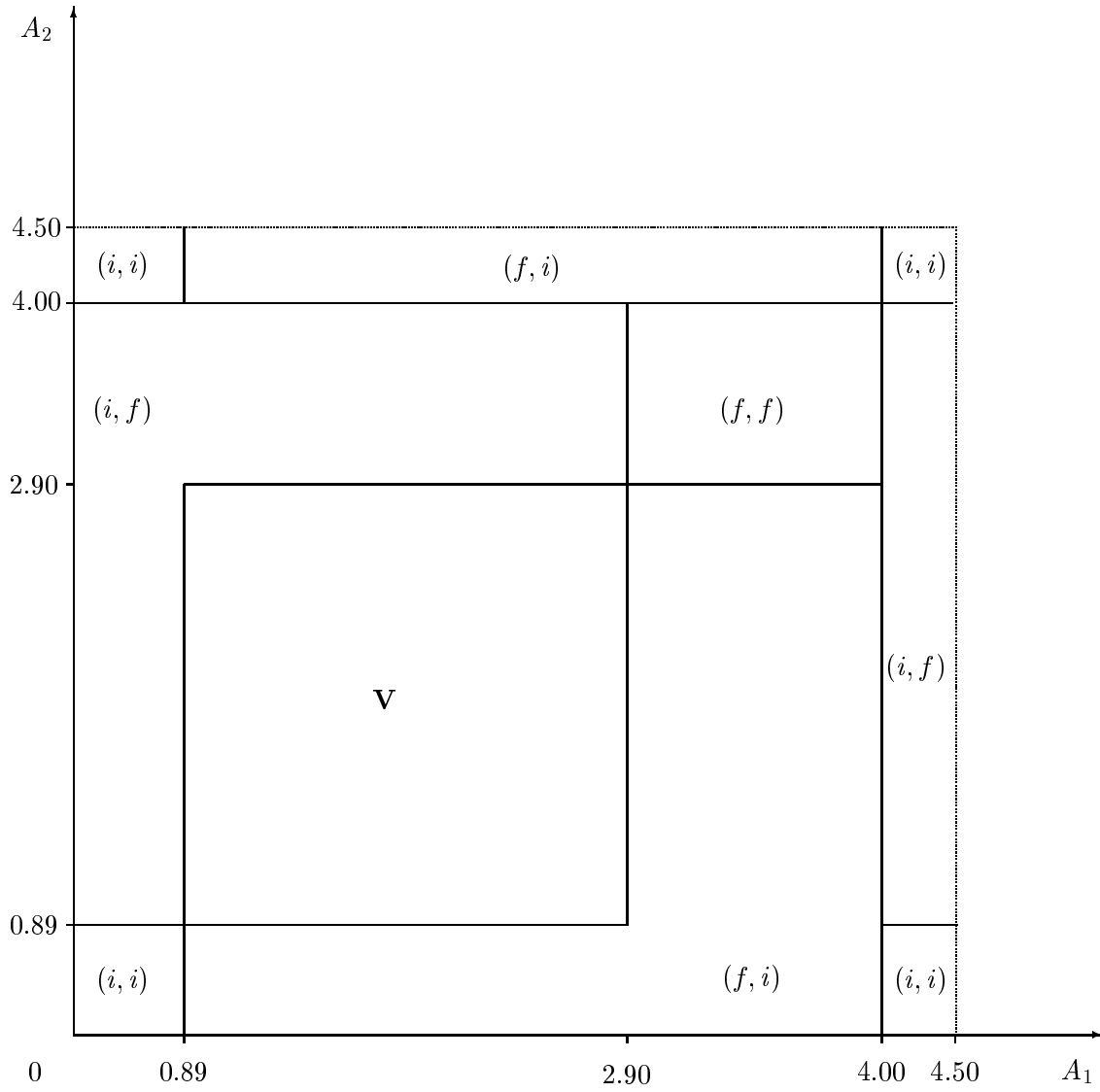
in V, (f, i) **or** (i, f).

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Figure 4

Equilibrium technological configurations in example 4, $x \in X_2$;

in **Y**, (f, f) or (i, i);

in **S**, (f, i);

in **T**, (i, f);

in **V**, (f, i) or (i, f);

in **W**, no equilibrium in pure strategies.

The plot has vertical axis A_2 and horizontal axis A_1. Vertical axis marks: 3.50, 2.51, 2.44, 0.90, 0.04. Horizontal axis marks: 0, 0.04, 0.90, 2.44, 2.51, 3.50.

Regions labeled: (i, i) (upper left), (f, i) (upper middle), (i, i) (upper right); **T**, **W**, (i, f), **V**, (i, f) (middle band); (i, i), (f, i) (lower middle); (i, i) (lower right); **Y** (lower left box); **W** and **S** (lower middle column).
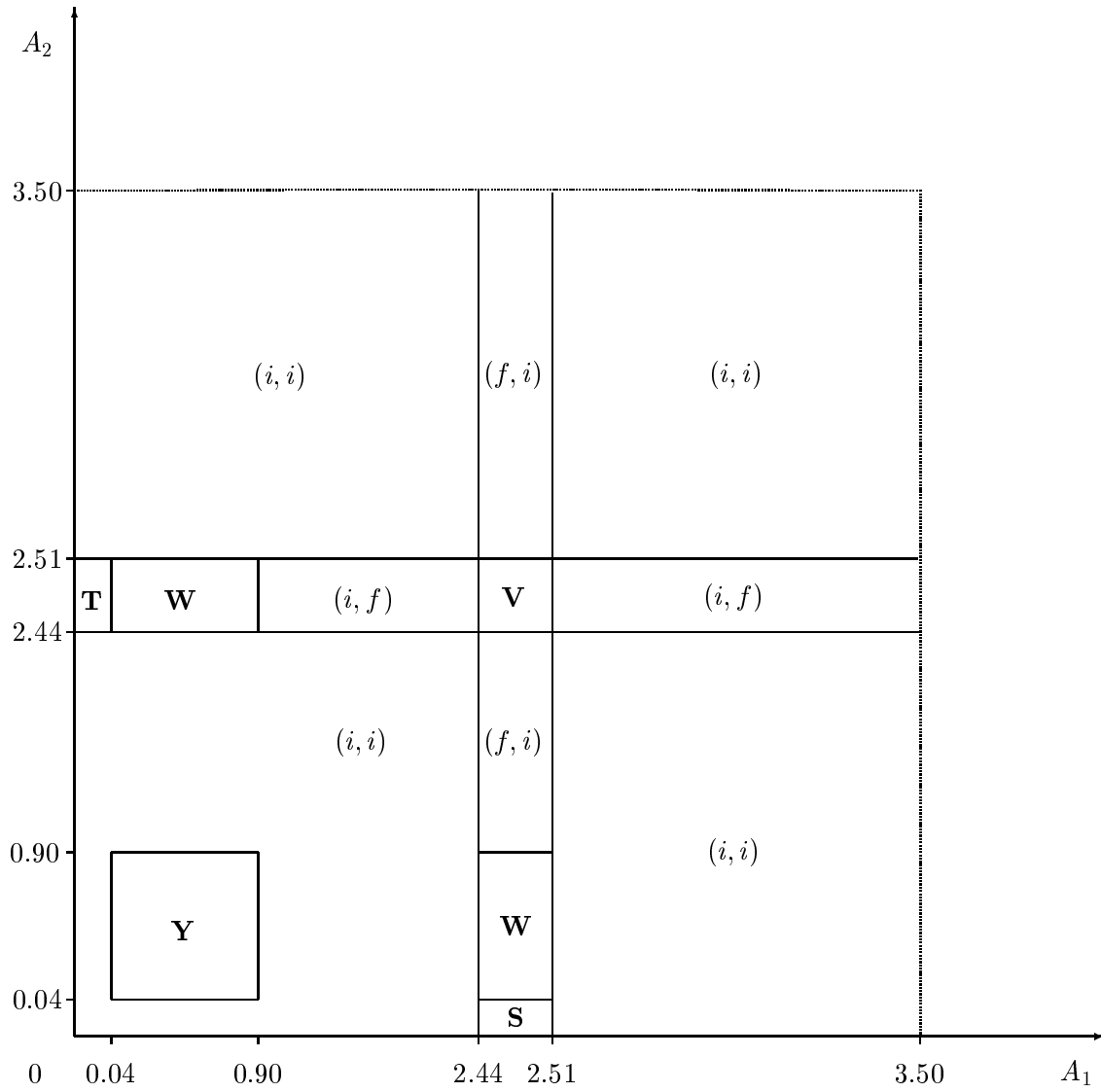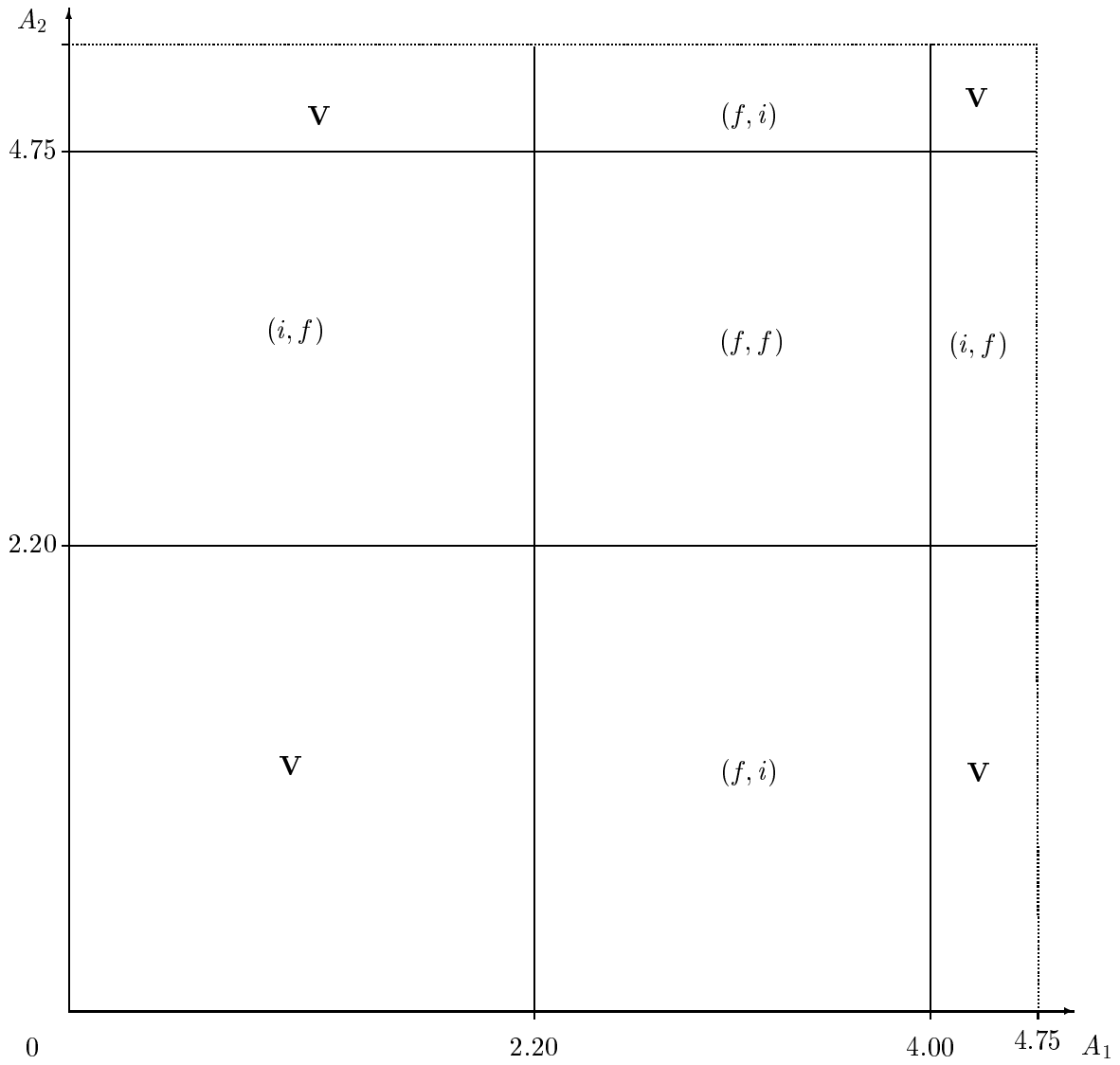

FIGURE 5

Equilibrium technological configurations in example 5, $x \in X_3$;

in V, (f, i) or (i, f).

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